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Innovative Application of O.R.

Tying mechanism for airlines' air cargo capacity allocation

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ABSTRACT

Airlines commonly experience the problem that the sum of freight forwarders' orders exceeds the airline's fixed capacity for hot-selling routes, while the orders are usually <50 percent for underutilized routes. Airlines cannot dynamically change flights to address the imbalance, since they have to serve passenger traffic when carrying cargo in the belly space of passenger flights. The imbalance problem is likely to become even more severe when the number of wide-body passenger aircraft increases in the near future, as expected by the International Air Transport Association (IATA). Motivated by a joint project with a large airline, we propose a tying mechanism for capacity allocation by integrating hot-selling routes and underutilized routes. The strategic foreclosure theory is adopted in the proposed mechanism. Some forwarders are selected as the partners to whom more capacity of hot-selling routes are allocated with the condition that they will order more underutilized routes. Other "excluded" forwarders temporarily operate underutilized routes. By observing the cost structure information of forwarders, we design the tying mechanism for air cargo capacity allocation and derive the closed-form optimal solution. Using data from the airline, we demonstrate that the proposed tying capacity allocation mechanism is very effective.

1. Introduction

Air cargo is an increasingly significant source of revenue for airlines. Worldwide, the air cargo transportation grew 50 percent faster than the passenger traffic (Wong, Zhang, Hui, & Leung, 2009). Boeing (2007) forecasts that the air cargo market will grow at 6.1 percent per year and triple by 2025. In particular, some markets are expected to grow even faster, for example, intra-Asian freight will grow at 8.6 percent per year and China is estimated to grow at over 15 percent. The dramatic growth in air cargo is attributable to many drivers, including increased global trade, greater demand for faster and timelier delivery, and firms' efforts to keep inventory low through frequent replenishments (Li, Tao, & Wang, 2009; Ou, Hsu, & Li, 2010).

An air cargo service supply chain mainly consists of airlines, freight forwarders, and shippers. The shippers, who may be individual customers or companies (e.g., Toyota and Nokia), send their shipments to freight forwarders. The freight forwarders (e.g., UPS in the USA and Deppon in China) book cargo capacity from airlines and integrate and consolidate cargo to be shipped according to shippers' requirements. Airlines operate dedicated freighters and passenger and cargo combination aircraft (or passenger flights) to provide cargo capacity to forwarders and shippers. In such a service supply chain, freight forwarders are often quite fragmented, and airlines often possess dominating power over forwarders, especially in the hub region within a hub-spoke network.

The airline sells cargo capacity[1] to forwarders through pre-allocation, contract and spot market sales (see Gupta, 2008 for details). Although airlines may sell directly to shippers occasionally, more than 60 percent of domestic and 90 percent of international air cargo capacity is sold to forwarders (Amaruchkul, Cooper, & Gupta, 2011). The airline pre-allocates the planned capacity on each route to forwarders based on their performances in the preceding year. Forwarders need the allocation information to expand their warehouse and determine the fleet size of road feeder service for the next planning period. Forwarders usually enter into contracts with airlines for purchasing dedicated freighter capacity one season or half year ahead when they have stable cargo sources. In the spot market, forwarders book cargo capacity from airlines 5 hours to 1 week ahead. Considering the possible *cancellation* and *variable tenders* from forwarders, airlines *overbook* cargo capacity and adopt *accept-or-reject* policies to maximize the expected revenue after demand is forecasted (Amaruchkul, Cooper, & Gupta, 2007). Airlines

[1] Air cargo capacity means the cargo space in units of tons, comprising the space in the belly of passenger flights and dedicated freighters. The cargo capacity on one route, in this paper, means the cargo space of a scheduled flight on a one-way origin and destination pair (OD pair).

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manage network capacity via several branches, each of which operates its own regional business. For each branch, there are many representatives responsible for allocating and selling the capacities of 6–15 routes to forwarders. For each route, the airline usually collaborates with several forwarders to sell capacities. At the beginning of a planning period, the Department of Cargo Capacity Planning assigns network capacity to each branch. After that, each representative allocates the capacity on the managed routes to forwarders according to their performances in the preceding year. Once the forwarders accept capacity quotas, they have to commit to the allotments 12 months ahead (Amaruchkul et al., 2011).

Airlines often face the challenging problem that the capacity on some routes is insufficient to meet forwarders' orders, while other routes have idle capacity. According to the Civil Aviation Administration of China, the capacity booking rate for hot-selling routes, which count for 24.5 percent of all routes, is over 100 percent, but the utilization rate for underutilized routes, which count for 33.6 percent of all routes, is $<$50 percent. For example, the cargo capacity of the early morning passenger flight from Guangzhou to Changsha is tight, while the cargo capacity of all passenger flights from Guangzhou to Sanya is idle. Multiple reasons contribute to this imbalance. The first is imbalanced interregional and international trade. Such an imbalance is apparent in cargo flows between Asia and North America. The second is that air cargo flows, unlike passenger flows, are unidirectional, which aggravates the effect due to the first reason. Another reason is the unmatched demands for passengers and cargos when carrying cargo in the belly space of passenger flights. Frequent flights established to serve strong passenger demand may cause a large amount of idle cargo capacity in the belly space. This problem is expected to worsen in the near future when the number of wide-body passenger aircraft will sharply increase (source: International Air Transport Association-IATA). The imbalanced cargo capacity utilization for different routes is a common challenge for airlines. To deal with the inevitable and intractable problem of imbalanced capacity utilization faced by many airlines, a joint research project was conducted with a large airline. We observed that, in reality, forwarders are thirsty for the capacity on hot-selling routes for their high margin. Forwarders would not accept any more capacity on underutilized routes when their marginal profit is equal to marginal cost in the pre-allocation stage. In such a situation, airlines can use tying mechanisms to make the allotment of tight capacity conditional upon ordering extra idle capacity. With a tying mechanism, a firm with a monopoly on one resource can use the leverage provided by this power to improve the sales of the second resource (Whinston, 1990). Doling out capacity through a tying mechanism has occurred in industries ranging from personal computer to digital video. For instance, Sony has tied one kind of unpopular digital camera with a very popular video camera when selling to its wholesalers (Sony, 2003).

Other possible strategies may be suggested to airlines to deal with such problems of imbalanced demand. The first possible solution is the pricing mechanism, which is necessary and effective, but has its own limitation. Ultimately, its effect depends on the price elasticity of demand. Furthermore, a deep cut in prices regarding the capacity on underutilized routes may result in very low, even unworthy, profit margins. The second possible approach is for airlines to conduct a combinatorial auction, requesting forwarders to submit bids for the combinations of different routes' capacity. Although this may sound appealing, users encounter a number of difficulties (Pekec & Rothkopf, 2003). (1) The IT infrastructure and the implementation of a combinatorial auction will incur a significant cost. (2) The resulting revenue, though expected to be higher, is uncontrollable, which is typical of sophisticated game activities. (3) It is difficult for an airline to conduct such an auction. Forwarders dislike the complicated gaming activities.

Therefore, the suggested tying capacity allocation mechanism is effective and practical for airlines. The basic process of the tying capacity allocation works as follows. (1) Routes partition. Network-wide routes are partitioned into many blocks of routes. Each representative manages one block (i.e., 6–15 routes). (2) Routes tying. It is pragmatic to tie one hot-selling route (Route A) with one underutilized route (Route B). An effective rule is to tie the most hot-selling route with the most underutilized route, and then tie the second hot-selling one with the second underutilized one, and so on. (3) Allotment design. Representatives use the forwarder's performance in the preceding year to work out tied allotments for that year. Some promising forwarders are selected as partners, while others are temporarily "excluded" from Route A and only operate Route B. The partners are allocated more capacity for Route A (the share from the "excluded" forwarders) and allocated extra capacities for Route B without any loss of profit. By using the tying capacity allocation mechanism, airlines can increase their profit because Route B capacity is better utilized. The airline has dominating power to implement the tying capacity allocation because it is monopolistic within the hub region in a hub-and-spoke network. The "excluded" forwarders especially do not lose all the hot-selling routes due to their different strengths in different blocks of routes.

As far as we are aware, this is the first paper to model the problem of tying capacity allocation. Our model captures a primary issue—how to tie two types of capacities for allocation. A tying mechanism for air cargo capacity allocation is designed, and a closed-form optimal policy can be derived by our model. In addition, some important observations are reaped from the air cargo industry. We find different cost structures that the forwarders operate hot-selling and underutilized routes through an airline's dual-channel system of air cargo sales. In addition, we derive the cost parameters of forwarders from their purchasing records. Such information can then enable airlines to select partnering forwarders and tailor offers to forwarders.

The rest of the paper is organized as follows. In Section 2, we review the related literature. In Section 3, we define the problem and formulate it into a nonlinear programming model. In particular, we present the important observations that enable the estimation of the forwarder's cost structures and related parameters. In Section 4, we develop a solution procedure and derive the closed-form optimal solution. In Section 5, we discuss a few possible extensions of the basic model. A case is reported in Section 6. We then summarize the paper in Section 7.

2. Literature review

Although there is considerable interest in tying capacity allocation mechanisms among practitioners, there is essentially no academic research that relates directly to this topic. The related literature is studies regarding air cargo capacity management, capacity allocation, and tying (or bundling) sales.

2.1. Air cargo capacity management

The existing air cargo capacity management literature contains studies on *overbooking*, *accept-or-reject* policies, and *contracting*, whereas research on air cargo capacity *pre-allocation* is extremely limited. A leading research stream is overbooking, in which the airline determines overbooking levels based on calculations of *no-shows*, *cancellations*, and *variable tenders*. For instance, Kasilingam (1997) proposed a model for optimal overbooking levels of air cargo with consideration of discrete and continuous probability distributions of capacity. Popescu, Keskinocak, Johnson, LaDue, and Kasilingam (2006) presented a nonparametric distribution estimation and forecasting method for calculating the show-up rate for cargo booking and compared the proposed discrete distribution with the normal distribution. Wang and Kao (2008) developed a fuzzy knowledge system to determine overbooking levels based on fuzzy reasoning. Another research stream investigated accept-or-reject policies, in which airlines accept or reject a booking request to optimize the expected revenue.